GEOLOGY

Title: **Dendrochronology in the Yellowstone Fossil Forest**

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Objectives: Map petrified wood localities and interpret ecological and depositional histories of various fossil forests using: 1.) Annual growth ring series (crossidentification, standard descriptive statistics, tree age determinations); 2.) Taxonomy; 3.) Taphonomy; and 4.) Rock descriptions. Most recently, attempts have been made to use botanical features from specific horizons at the Specimen Creek locality to determine stratigraphically equivalent horizons at an exposure 1.3 km to the southeast.

Findings: Fieldwork was conducted at the Specimen Creek exposure. Data as previously described was recorded on 71 fossil stumps. No specimens were collected. One stump displaying apparently in situ root growth along the face of a rock was photographed.

Title: **Investigation of CO_2 Emissions Related to the Yellowstone Volcanic/Hydrothermal System**

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Additional Investigators: Cindy Werner

Objectives: 1.) To estimate the CO_2 emissions due to the Yellowstone volcanic/ hydrothermal system. 2.) To monitor background temporal variability of CO_2 emissions, and how variations are related to changes in hydrothermal and seismic activity. 3.) To study the spatial distribution of CO_2 emissions and investigate controls on spatial heterogeneity of gas emissions; and 4.) To monitor gas chemistry including carbon and helium isotopes to gain a broader understanding of the sources of magmatic gases and interactions with the hydrothermal system.

Findings: During the summer of 1997, extensive flux measurements were completed in the Mud Volcano thermal area. A statistical sampling plan was implemented in order to measure a statistically valid flux for the area, and in order to better understand spatial heterogeneity in the park and in that area in particular. Using the statistical sampling plan to estimate an overall CO_2 flux from the whole Mud Volcano area yielded an estimate of 10^9 mol CO_2 /year as a time-averaged flux. Using heat flow estimates for the whole park we also estimated, based upon our summer work in Mud Volcano, that the total CO_2 flux parkwide could be as large as 10^{12} mol CO_2/y. This value, roughly equivalent to 10-20 average coal-burning power plants, is a large flux compared to most volcanoes. The largest flux ever measured at a volcano is the flux measured at Etna (Italy, 1 x 10^{12} mol CO_2 /y), and thus, if our estimate for the park is correct, this suggests that park carbon emissions may be a significant contributor to volcanic/geothermal emissions of CO_2 worldwide. More measurements are needed to confirm this hypothesis.

In 1998, a stratified-adaptive sampling plan was designed to estimate CO_2 degassing in Yellowstone National Park, and applied in the Mud Volcano thermal area. The stratified component focused effort in regions with the most spatial heterogeneity (high-flux regions), without biasing our estimate for the total region. The maximum and minimum measurements for vent and diffuse fluxes were 2.4 x 10^9 and 6.3 x10^4 mols/ yr, and 32,000 and 4.0 g/m^2 day, respectively. Fluxes observed in most vegetated regions of Mud Volcano were similar to values reported by agricultural studies (<38 g CO_2/m^2 day). However, we also found a few high-flux vegetated sites (up to 5,000 g/m^2 day) that are likely thermal features that have waned in thermal activity, yet are preferred pathways for degassing of deep CO_2. Vent degassing (2.4 x 10^9 mols/yr) accounts for ~50% of the total degassing observed at Mud Volcano (4.9 x 10^9 mols/yr). Using estimates of magma emplacement rates from other studies, we calculated a rough CO_2 flux for the entire Yellowstone system based on the relationship between heat flux and CO_2 degassing. We approximated an emission rate of 7 x 10^{11} mols/yr, which is comparable to globally important volcanic fluxes.

Temporal variation of CO_2 emissions was observed to correlate with soil moisture and environmental conditions. Preliminary investigation of the CO_2 emissions in the Upper Geyser Basin, Mammoth Springs, Roaring Mtn., Washburn Springs, Crater Hills, and the Lamar River Valley suggest that diffuse degassing is highest in acid-sulfate and travertine precipitating regions, and lowest in regions of silica precipitation and sulfur flows. No attempt has been made to estimate vent emissions in these areas.

Title: **Recognizing the Signatures of Hyperthermophilic Biofilms: Geyserite, Epithermal Deposits, and Ancient Cherts**

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Objectives: Our primary objective is to establish criteria that will facilitate the recognition of ancient geyserite stromatolites and subsurface hydrothermal deposits that formed in the presence of hyperthermophilic biofilms. Our approach is to characterize the biogeochemical signatures of modern hyperthermophilic communities using a combination of field, experimental, and analytical techniques (i.e., molecular phylogeny in collaboration with N.R. Pace and co-workers, electron beam ultrastructural analysis, quantitative mineralogy and petrography, and isotopic and biomarker compound analysis). By studying how modern hyperthermophilic ecosystems are converted to their paleobiological counterparts, we can identify the processes responsible for the preservation of microfossils, chemofossils, and sinter stromatolites.

Identify the processes by which hyperthermophilic biosignatures are preserved in the rock record requires understanding of mechanisms of initial preservation and subsequent diagenetic alternation. Our goal is to establish a framework within which the paleobiology of hyperthermophilic communities fossilized in hydrothermal sinter and epithermal deposits can be identified and properly interpreted.

Findings: In 1997, we found that hyperthermophilic biofilms are distributed on the sediment that accumulates at the bottoms of thermal spring pools and on the surfaces of permanently submerged geyserites and geyserites that occur in periodically submerged splash zones around thermal springs. Scanning electron microscopy (SEM) analysis reveals that in each of these types of microenvironments, the biofilms are composed primarily of filamentous hyperthermophiles surrounded by a polysaccharide matrix. SEM images show that filamentous biofilms (< 1 micron thick) display different architectures that can be correlated with the specific hydrodynamic conditions of the microenvironment. Having characterized the distribution and ultrastructural characteristics of hyperthermophilic biofilms within Octopus Spring, we plan in the coming year to compare hyperthermophilic biofilms from a variety of geochemically diverse thermal springs. Additional electron microscopy analysis indicates that the fidelity of microfossil preservation depends upon the fossilization mechanism, and on the environmental conditions within which silicification occurs. Our current aim is to identify the exact mechanisms that enhance microfossil and stromatolite preservation in thermal spring and geyserite deposits located within Yellowstone National Park, Wyoming.

In 1998, we identified members of hyperthermophilic microbial populations found in silica-depositing springs using molecular phylogeny and various microscopy methods (optical, scanning and transmission electron microscopy). We characterized distribution of hyperthermophilies on natural sinters and on various substrates within different microenvironments (subaqueous and subaerial) of several pools. We also characterized the biogeographic distribution of dominant community members for several silica-depositing springs located in different thermal basins using molecular phylogenetic analysis.

Title: **Relationship Between the Geochemistry of the Waters and the Geochemistry and Petrography of the Precipitates Within Hot Water Travertine Systems**

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Additional Investigators: Sean A. Guidry

Objectives: The primary objectives of this investigation are to analyze the water-carbonate precipitate relationships within hot water travertine systems and the water silica relationships within some of the silica rich systems. More specifically, the goal is to delineate the mineral species, individual crystal habits, morphologies of crystal habits, and the elemental and stable isotopic composition of the solids that precipitate within the waters of a variety of travertine and geyserite systems. In addition, we are studying the microbial community and its relationship to the mineral precipitates. We are concerned with the preservation of microbes in these systems and the ability to recognize their remains with increasing alteration of the mineral precipitate. Of particular interest is whether the microbes impart a recognizable geochemical signature to the mineral precipitates. Another area being emphasized is the search for and significance of nanobacteria within the system.

Findings: Analyses to date strongly indicate that there are significant constraints on the use of geochemical signatures to indicate the paleoenvironmental conditions at the time of travertine precipitation (Chafetz and Lawrence, 1994). The composition of the waters change temporally and laterally within individual travertine systems. These findings have been substantiated with analyses of water and precipitates from other hot spring systems. Analogous analyses of siliceous systems are in progress. Microbial organisms actively promote travertine precipitation in addition to acting as an important substrate for nucleation and crystal growth. Study of the preservation of the microbes is in progress.

Title: **Geochemical Baselines in the Greater Yellowstone Area**

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Additional Investigators: Robert C. Carlson, William Miller, Harley King, Richard Sanzolone

Objectives: 1.) Provide objective, unbiased geochemical baseline data for about 50 chemical elements determined in samples of rock, active stream-sediment, water, plants, and animal scat collected from scattered localities throughout Yellowstone National Park (YNP) and the adjacent U.S. Forest Service lands. Baselines to include raw data and interpretive report. 2.) Identify the sources of anomalous concentrations of selected elements, such as geothermal features, past mining, and recreation. 3.) Determine the chemistry of selected elements in the food chain and how these elements may impact the health of wildlife in the park.

Findings: Samples of stream sediment, rock, water, and/or animal scat have been collected from as many as 330 sites (136 sites in 1998) in and around YNP. These samples have been analyzed for as many as 50 elements. In the northeastern part of the park, weakly anomalous levels of elements related to mineralized rock or to past mining in the Cooke City area have been detected in samples from the Soda Butte Creek drainage basin. These weak anomalies extend to the confluence of Soda Butte Creek with the Lamar River, where sediments from that stream with background levels dilute the anomalous concentrations from Soda Butte Creek to background levels.

In the geothermal areas of the park studied to date (both fossil and active), a common suite of elements are generally present in sediment downstream from each locality. Concentrations for some elements, such as arsenic and fluorine, are significantly elevated as compared to background levels.

Analysis of elk and bison scat shows anomalous concentrations of elements associated with geothermal features for those animals grazing near such features, indicating that animals living in geothermal areas are ingesting significant levels of elements such as arsenic and fluorine. The effects of fluorine on elk have been documented by others. The effects of other elements on elk or other animals are not known.

Sampling is continuing to better define and understand the sources of anomalies.

Title:	**Volcanology and Petrology of the Yellowstone Plateau Volcanic Field**

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Additional Investigators: Wes Hildreth

Objectives: To understand the origins and eruptive mechanisms of late Cenozoic volcanic activity in the region of Yellowstone National Park, and to complete systematic geologic-mapping studies carried out intermittently in the park region since the 1960s.

Findings: No new work was done on this project in 1998. USGS Professional Paper 729-G is now nearly ready for publication by the USGS Western Publications Group, awaiting only final digital details on the largest geologic-map plate.

Title:	**Mapping the Mineralogy Vegetation and Microbiota of Yellowstone National Park Using Imaging Spectroscopy**

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Objectives: This task uses remote data gathered by an airborne spectrometer to map the distribution of minerals, vegetation cover types, and thermophilic bacteria in selected areas of Yellowstone National Park. The derived maps are analyzed for the surficial expression of underlying geologic processes and the geologic controls on vegetation distribution. The task objectives are: 1.) Use the spectroscopic remote sensing data to map the distribution of minerals within the covered areas of the park and relate their presence to the geologic processes leading to their formation. 2.) Use spectroscopic remote sensing data to map the distribution of biologic materials and examine the relationships between geologic controls on biologic cover.

Findings: This task uses remote sensing data gathered by an airborne spectrometer to map the distribution of minerals, vegetation cover types and thermophilic bacteria in selected areas of Yellowstone National Park. The remote sensing data was collected by the Airborne Visible and Infra-Red Imaging Spectrometer (AVIRIS) at 17 meter resolution in 1996 and at higher spatial resolution in 1998 (approximately at 1.6 meter pixel size). Initial mapping has been completed using 17 m data for minerals and vegetation cover types. The 1996 AVIRIS data was also used to detect the presence of microorganisms growing in the heated water flowing out of the park's hydrothermal geysers and pools. High spatial resolution data has been examined in a preliminary manner. A compositional comparison of the higher spatial resolution data with the lower spatial resolution data show good agreement between the minerals detected from each flight. The minerals detected indicated the type of alteration occurring in the various geyser basins of Yellowstone National Park. The variety of alteration minerals occurring within the areas of the park covered by the airborne spectrometer indicate differences in the pH and temperature of hydrothermal fluids. The high-resolution data reveal even finer details of the distribution of alteration minerals within the basins. The high-resolution data collected in 1998 show a greater variation in reflectance signatures from bacterial mats, indicating that the possibility of mapping bacterial species of bacterial mat composition from such data. Vegetation maps of forest and non-forest cover types derived from AVIRIS 1996 data have been developed. For FY00, the proposed work includes final stages of field verification of maps of materials derived from the AVIRIS 1996 data. In addition, material maps for two selected areas will be derived from the high spatial resolution data (Old Faithful and the Norris Geyser Basin/Roaring Mountain). Publication of existing draft manuscripts is expected to be completed. Georectification of imagery will be performed in order to produce material maps that can be provided directly to the National Park Service and the general public through the Internet. Finally, maps of biologic materials will be compared with existing geologic information in order to examine the influences of underlying geology on the park's vegetation cover.

Title:	**Investigations of Sediments of Lakes in Yellowstone National Park for Records of Past Climate and Environmental Change**

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Additional Investigators:	Cathy Whitlock

Objectives: Investigate past changes in climate and environments in Yellowstone National Park based on geochemical, mineralogical, and biogenic components of lake sediments.

Findings: Samples were collected at 10 cm intervals from four long cores, and eight short (surface-sediment) cores by Cathy Whitlock, University of Oregon, for pollen and fire-history investigations. The long cores are from Cygnet Lake, Trail Lake, Slough Creek Pond, and Blacktail Fen. The short cores are from Cascade Lake, Dryad Lake, Duck Lake, Goose Lake, Grizzly Lake, Lake of the Woods, Sylvan Lake, and Wrangler Lake. Concentrations of organic carbon (OC) and calcium carbonate ($CaCO_3$) were measured in all samples from all cores. Only sediments from lakes in the northern range of the park (Blacktail Fen and Slough Creek Pond) contain measurable amounts of$CaCO_3$. The $CaCO_3$ contents of sediments in Blacktail Fen have remained high (50-75%) throughout its history as an open lake and, most recently, as a wetland. The OC contents of sediments in Blacktail Fen have fluctuated considerably throughout its history. The core has not yet been dated by radiocarbon methods, but contents of both $CaCO_3$ and OC were much more variable in the lower half (4-7 m) of the core suggesting that environmental conditions in the lake, and perhaps climatic conditions in the area of the park, were much more variable during the early history of the lake. Both parameters are much less variable in the upper three meters of the core. The $CaCO_3$ contents of sediments in Slough Creek Pond are lower, and contents of OC higher, than in sediments from Blacktail Fen. The $CaCO_3$ content in the lower two meters of the core from Slough Creek Pond are slightly higher (30-40%) than in the upper two meters (20-30%). The OC content increased steadily throughout the history of Slough Creek Pond, from <5% at the base of the core to 20% at the top. The OC content of sediments in Cygnet Lake increased dramatically about 9,000 years ago, from <4% to more than 15%, then decreased slowly to about 10% at the top of the core. The OC content of sediments in Trail Lake increased slowly but steadily from <2% at the base of the core to about 15% at the top. The OC content of surface sediments in the eight lakes sampled ranged from a low of 6.3% in Duck Lake, to a high of 23.1% in Wrangler Lake, with an average of about 10%.

The organic matter in sediments from Slough Creek Pond and Trail Lake, at opposite ends of the park and in very different geologic, hydrologic, physiographic, and climatic settings, was analyzed by Rock-Eval pyrolysis. This technique measures a hydrogen index and oxygen index that can be used to distinguish hydrogen-rich, oxygen poor algal organic matter from hydrogen-poor, oxygen-rich terrestrial organic matter. The results show that the organic matter in sediments in both lakes is almost entirely algal, that is, produced in the lake. This conclusion was further substantiated by the carbon and nitrogen-isotopic composition of the organic matter. Isotopic analyses have been completed on most samples and indicate that the organic matter in sediments from the other lakes, like that in Slough Creek Pond and Trail Lake, is of algal origin.

Because the waters of Blacktail Fen and Slough Creek Pond are carbonate-rich, both of these lakes have always had a rich mollusc fauna (snails and clams). The carbon and oxygen-isotopic composition of the $CaCO_3$ in the shells of these molluscs can provide valuable information about changes in salinity and hydrology of the lake, and of sources of organic matter and changes in productivity in the lake. The isotope analyses are currently in progress and should be completed by the summer of 1998. Mineralogical analyses by X-ray diffraction also are in progress and should be completed by this summer.

Title:	**The Silicification of Plants in Hot Springs, Yellowstone National Park**

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Additional Investigators:	Alan Channing

Objectives: 1.) Assess the possible environments of higher plant silicification, burial, and diagenetic alteration associated with surface geothermal activity. 2.) Investigate the extent and nature of silica mineralization within plant material of hot spring environments. 3.) Determine physicochemical, biochemical, and physiological controls on silica permineralization at cellular to structural levels. 4.) Compare silica fabrics from Yellowstone plants, sub-fossils, and fossils with those of a 400 million year old fossil hot spring deposit at Rhynie, Aberdeenshire, Scotland. 5.) Investigate the physiological adaptations of modern plants to the sedimentary, hydrogeological, and geochemical regimes of modern hot springs, and assess the probability of similar adaptive strategies in early terrestrial ecosystems.

Findings: 1.) SEM observation of plant material displaying incipient silica mineralisation provides evidence of intracellular nucleation, polymerisation, and aggregation of sub-micron spheres via colloidal mechanisms. 2.) Silica deposition fabrics and the degradation of plant materials are mediated by the interplay between a suite of physicochemical parameters notably pH, temperature and cation concentration. 3.) Rapid vertical, lateral and temporal variation in substrate/groundwater temperature, moisture, and geochemistry indicate a degree of tolerance to those conditions in colonizing plants. Xerophytes, halophytes, and aquatics occupy and are silicified within definable hot spring sedimentary facies. 4.) Light microscopy reveals evidence of "ghost" microspheres in cell lumens of Rhynie plants. XRD analysis of picked intracellular separates indicate the dominance of non-crystalline silica phases in initial cellular permineralisation. Microcrystalline silica phases dominate Rhynie material. Cell function, particularly as it relates to cell wall thickness and stability of component organic compounds in hydrothermal fluids, greatly influences the degree of cellular and structural replication/preservation during permineralisation.

Title: **Biosedimentology, Microbiology, and Geochemistry of Modern Hot Springs**

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Objectives: To understand basic fossilization processes in subaerial thermal springs over a range of conditions in temperature, pH, composition, etc., and to observe the effects of early diagenesis on the biosignatures captured with sinter deposits.

Findings: To date we have established a basic observational database that reveals the types of preservation (microbial fossils) occuring in siliceous, travertine, and Fe-oxide precipitating springs, and the transistional record of deposits that have undergone initial diagenesis.

Title: **Geochemistry and Geochronology of Eocene Potassic Volcanism in the Absaroka Volcanic Field**

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Objectives: Our objective is to carry out a geological and geochemical transect across the northern part of the Eocene Absaroka volcanic field. Because the Absaroka volcanic rocks record one of the most voluminous and compositionally diverse magmatic episodes to affect the Cordillera during the Eocene, the results obtained from this study will improve our knowledge of the ages, compositions, and petrogenesis of Tertiary magmatism in the northern Rocky Mountains. This, in turn, will provide insight into the fundamental problem of how rock suites with arc-like geochemical features can form in such different tectonic environments, and possibly in the absence of contemporaneous subduction. The targeted areas in Yellowstone National Park are the Mt. Washburn-Observation Peak volcanic center, the Sepulcher Mountain-Electric Peak eruptive center, and the Sylvan Pass-Eagle Peak eruptive center.

Findings: To date we have collected approximately 90 fist sized rock specimens from the targeted localities in Yellowstone National Park. Most of these have been cut for thin sections and analyzed for major and trace element contents. Currently, about 15 samples are awaiting $^{40}Ar/^{39}Ar$ age determinations, which should be completed by the end of summer 1999. Further, about 25 samples are currently awaiting analyses for Sr, Nd, and Pb isotopic ratios, which should also be completed this summer. In conjunction with samples from outside of the park, we have found that there appears to be no systematic relationships between geographic position of Absaroka eruptive centers with geochemical indicators of subduction-derived fluids. Whereas all samples have high values for ratios commonly associated with subduction zones (e.g., Ba/Nb), samples from centers to the east of the park (and presumably east of the Eocene oceanic trench) have the highest values. This is inconsistent with smaller degrees of volatile fluxing to the east. Thus, the Absaroka volcanic field may have a more complex origin than a simple subduction related volcanic arc.

Title: **Crustal Structure and Composition of Yellowstone National Park and their Relation to Hydrothermal and Seismic Activity**

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Objectives: The objective was to collect aeromagnetic data along east-west lines spaced 400 m apart at an elevation 700 ft. above the terrain in order to delineate faults, alteration that might record fossil hydrothermal activity, volcanic flows, and sedimentary basins in YNP.

Findings: Unmapped faults within the caldera, that might represent the ring fracture system that localized lava flows and might be associated with hydrothermal explosion craters, have been delineated. It is not clear whether they are seismically active. Alteration associated with the major hydrothermal systems, as well as in Yellowstone Lake, have been identified. Combination of the aeromagnetic data with geologic, geochemical, and remote sensing data will help delineate lava flows and fossil hydrothermal systems. This analysis will help provide a clearer picture of the history of hydrothermal activity in the park.

Title: **Geology and Chemistry of Hot Spring Deposits**

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Additional Investigators: Dr. Joseph Moore, Dr. Roy Mink

Objectives: To characterize the geologic and geochemical environments of hot spring deposits in Yellowstone National Park.

Findings: Collecting was carried out in 1997 at Calcite Hot Springs. During 1998, a report titled "Chemical Analyses of Geologic Samples: Calcite Hot Springs, Yellowstone National Park," was submitted to Yellowstone. This report, by Andrew L. Glandon, was prepared as a senior capstone research project at Pacific Lutheran University. SEM and ICP data were collected, but further chemical analyses are required before definitive conclusions can be reached about the deposits of this fascinating site.

Samples collected are stored in the Department of Geosciences at Pacific Lutheran University.

Title: **Aqueous Geochemistry and Sediment Mineralogy of Selected Hot Springs, Yellowstone National Park**

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Objectives: 1.) To add to an existing data base of geochemical analyses of Yellowstone thermal features. 2.) To increase our knowledge of the mineralogy of hot spring sediments, with a focus on the clay rich deposits. 3.) To increase our understanding of the thermodynamics of clay mineral formation at the earth's surface.

Findings: Field data, sediment, and water samples were collected from hot springs and mud pots in the Mud Volcano, Norris Basin, Midway Basin-Rabbit Creek, Clear Water Springs, and Artist Paint Pots geothermal areas. Field measurements were made at 56 sites and included pH, temperature, conductivity, and oxygen reduction potential (ORP). GPS readings for each site were made by an SCA volunteer (S. Miller) under the direction of Ann Rodman. 29 water samples were collected and analyzed for total dissolved solids (TDS), H_2S, HCO_3, CO_3, Cl, SO_4, K, Na, Mn, Fe, Al, Mg, Ca, Li, SiO_2. X-ray diffraction analysis of 20 suspended sediment samples is in progress.

Title: **Interpretation of the Geochemistry of Thermal Waters (Old U.S.G.S. Project 9980-00292, Hydrothermal Fluids)**

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Objectives: 1.) To characterize the chemical and isotopic nature of the Yellowstone hydrothermal system. 2.) To gain an understanding of the evolution of this hydrothermal system and how it interacts with its magmatic heat source. 3.) To monitor possible chemical and physical changes in the hydrothermal activity.

Findings: We found a significant change in pH and sulfate, but not chloride, in waters from Sulfur Dust Spring over a three week period a few weeks before the start of the yearly hydrothermal disturbance [1995]. There was no detectable change in the composition of Sulfur Dust water during the disturbance. These observations may be important for gaining an understanding of the origin of the acid-chloride-sulfate waters at Norris. This type of water is absent in Upper and Lower Geyser Basins.

The project leader retired from the USGS in 1997 and the project was inactive in 1998. The project is not likely to be active in 1999. It would only become active in the event of some major geologic event that impacts the physical and chemical nature of the hydrothermal activity. R. Fournier is available to consult with other researchers about their research activities involving the Yellowstone hydrothermal activity.

Title: **Monitoring of Thermal Chloride Flux in Yellowstone National Park**

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Additional Investigators: Daniel R. Norton

Objectives: 1.) Monitoring of chloride flux, which is a proxy for heat flow from the magma underlying Yellowstone. 2.) To detect adverse changes in the thermal system due to proposed development of geothermal, gas, and oil resources adjacent to the park. 3.) To secure baseline data related to changes in the geothermal system caused by earthquakes and other tectonic events. Monitoring includes the total chloride flux as measured in the four rivers draining the park, as well as chloride flux from major thermal areas within the park.

Findings: We have secured a database from 1983 to the present (1998). Variations in chloride flux are related to discharge of the four rivers, which in turn, is related to precipitation in the park.

Title: **Analysis of Obsidian in the Northwestern USA**

Principal Investigator: Michael D. Glascock

See Archeology

Title: **A Petrological and Geochemical Analysis of the Tanker Curve Obsidian**

Principal Investigator: David Hansen

See Archeology

Title: **Geochemistry of Hot Spring Sinters and Microbial Mats**

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Objectives: 1.) Investigate geochemical variations in microbial mats, pore waters, siliceous sinters, and geyserites at different hot springs and thermal drainages in the park. Results will be compared with stage of silica diagenesis and geochemistry. 2.) Investigate the local hydrogeological characteristics of hot spring-influenced drainages. Results will be used to calculate mass balances for such drainages, to determine silica deposition rates in sinter mounds, and to determine interaction with local groundwater. 3.) Investigate seasonal changes in microbial communities and accompanying silica deposition rates.

Findings: Field work conducted during summer 1997 focused on confirming results from previous sampling periods on the diel changes in thermal springs, on continued monitoring of chemical and hydrogeological parameters in thermal drainages, and on evaluating the quality of data collected in previous work through comparison with other laboratories.

Diel Cycling of Chemical Parameters in Thermal Springs: Sampling at Chocolate Pots was conducted for a period of 48 hours during June 1997. Samples were collected hourly with a modified collection technique. The new collection procedure successfully prevented changes in component speciation providing more accurate results. In addition, a new, smaller pore size filter was used to better exclude colloidal and fine particulate material. Parameters measured were the same as previous sampling periods with one exception: ferrous and total iron concentrations, pH, dissolved oxygen, temperature, cation concentrations, and anion concentrations. Hydrogen peroxide was not measured.

Results failed to confirm diel cycling in ferrous iron concentrations at the Chocolate Pots vent, however cycling was observed to a limited extent distal from the vent. The lack of cycling at the vent suggests that the new, smaller filter size excludes particulate matter which had previously contributed to cycling of the ferrous and total iron concentrations. These results are consistent with published results on the concentrations of ferrous and total iron at the vent. Interestingly, a change is observed in the percent distribution of iron species at the distal sites. Ferric iron concentrations increase, even in the dissolved fraction, during daylight hours, driving cycling of total iron concentrations. The observed fluctuations are correlated with fluctuations in pH and dissolved oxygen.

Monitoring of Thermal Spring Chemistry: Octopus Spring, the site of ongoing hydrochemical and hydrogeological monitoring, was sampled in June and July of 1997. In addition, the piezometers around

Octopus Spring were sampled in July of 1997.

Field work conducted during summer 1998 focused on processes of silica accumulation in thermal springs and drainages, on identification of chemical and hydrogeological parameters identifying the sequence of deposition of these siliceous deposits, and the factors controlling diel variations in the chemistry of thermal springs. All samples collected not consumed during analysis are housed at the University of Montana. Specific results follow.

1.) Interaction of Thermal Spring Runoff with Shallow Groundwater and with Surface Water: Unlike surface runoff from thermal springs, subsurface runoff is not easily traced, yet is of ecological and managerial importance. In Yellowstone National Park, several streams drain thermal areas combining meteoric runoff with thermal runoff. Within the thermal runoff channels themselves, mineral precipitation removes components that become oversaturated upon cooling, leaving behind soluble components or those whose precipitation is kinetically inhibited. This modified runoff seeps into shallow groundwater resulting in further chemical modifications and mineral precipitation. Numerous stretches of Yellowstone streams are armored, including sporadic areas of Nez Perce Creek, Sentinel Creek, and Iron Spring Creek, as well as large portions of the Firehole River. Streambed armoring is evidenced by streambed sediments cemented in place by a gray-colored matrix; it is easily distinguished from the in-stream sinter deposits formed when surface thermal features drain into the river. Stream chemistry and nutrient cycling are impacted because the armoring forms an impermeable barrier along the streambed. Ground water and surface water samples were collected monthly and analyzed for major anions, major cations, and dissolved organic carbon (DOC). Temperature, dissolved oxygen, and pH were measured at each site. Initial results show lower DOC, fluoride, chloride, nitrate, and sulfate concentrations in surface water than in ground water. Streambed armoring is most likely caused by silica precipitation at the ground water-surface water interface.

2.) Silica Accumulation in Thermal Springs: Silica accumulation was studied in three outcrops of siliceous sinter. Results indicate that there are distinctive characteristics for each type of silica accumulating within sinters. Significant differences are noted among primary silica, cements found in microbially-textured sinters, and cements associated with breccias. The cause of these differences is under investigation.

3.) Studies into factors controlling diel cycling in thermal spring waters focused on hydrogen peroxide formation and decay. Results indicate that the formation is abiotically controlled by oxidation-reduction reactions involving iron. Decay is controlled by microbial processes. These results are exciting because they demonstrate a link between largely abiotic processes and biological processes.

Title:	**Geochemistry and Geochronology of Eocene Absaroka Volcanism**

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Additional Investigators:	Lawrence Snee, Anita Grunder

Objectives: To establish the petrogenetic history of the Absaroka Volcanic Province, by establishing the sequence of eruptive activity, and the major, trace element and isotopic variability of eruptive products. Age determinations by $^{40}Ar/^{39}Ar$ isotopic dating on ash-flow tuffs will provide regional age relationships, while ages from individual volcanic centers will link regional and local eruptive activity. Multi-elemental geochemical analysis will be used for geochemical modeling, to determine why and where melting (magmatism) occurred, and the relative contributions of crust, mantle, and asthenosphere.

Findings: Several ash-flow tuff deposits, presumed to be separate events, have been correlated, establishing age relationships of volcanic deposits in Yellowstone to the surrounding region, and providing a greater appreciation to the brief period when most of the middle Eocene volcanism occurred. Regional tuff deposits exhibit a north to south age relationship, the Slough Creek Tuff in northern Yellowstone erupted 49.5 Ma (million years ago), Pacific Creek and Slough Creek tuff (now correlated) erupted 48.8 Ma, and Two Ocean ash-fall erupted 47.5 Ma. The age of the Two Ocean ash-fall allows its correlation with the Blue Point ash-fall, a regional stratigraphic marker which has been established in the region surrounding Yellowstone. Newly established age relationships provide the information necessary to significantly revise the stratigraphy of the Absaroka Volcanic Province in Yellowstone. The oldest eruptions occurred in northern Yellowstone 53 Ma. Most of the eruptive activity took place between 49.5 and 47.5 million years ago, and the youngest volcanic deposits of this period are found on Two Ocean and Trident. Age relationships also indicate that a period of uplift and erosion during volcanic activity occurred about 48 million years ago. Geochemical analyses of samples from individual volcanic centers, observed in conjunction with geological features indicate that volcanism was produced during a period of extension. Melting is primarily derived from the lithospheric mantle with a minor amount of magma contributed from the asthenosphere. As magmatism progressed, contamination and derivation of magma from crustal and lower crustal sources occurred. Mafic ($<53\%$ SiO_2) lavas are highly potassic and occur throughout the province. Although more contaminated lavas are superficially similar to those produced in a subduction environment, mafic lavas have major and trace element chemistry, which are characteristic of within plate basalts produced in an extensional environment. Structural features produced by crustal extension during the Eocene are common features, including detachment faults in the Absaroka Province. Study and isotopic dating of dikes and intrusions cross-cutting a detatchment surface is also underway and provide an irrefutable link between the age of volcanism and local extension.

Title: **The Study of Siliceous Deposits in Geothermal Areas, USA & Japan**

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Additional Investigators: E. Izawa, S. Ogata

Objectives: This study, which concluded in mid-1998, was aimed at comparing the morphology, structuring, and formation of siliceous sinter around hot springs in YNP and Japan.

Findings: The results included the careful study of a 500,000 year old sinter deposit, called the Ikiryu Sinter, on the island of Kyushu, Japan; examination of sinters deposited at several geothermal power plants on Kyushu; and examination of modern sinters on Kyushu and northern Honshu. In addition, Japanese scientists made visits to YNP in the summers of 1996 and 1997. The Ikiryu sinter contains abundant, well-preserved bacterial structures that allow a thermal zonation of the sinter deposits.

Title: **The Structure, Facies, and Deposition of Siliceous Sinter around Thermal Springs: Implications for the Recognition of Early Life on Earth and Mars**

Additional Investigators: Deena Braunstein

Objectives: 1.) To study the textures and structuring of siliceous sinters deposited around hot springs and to determine the physical and chemical controls on sinter deposition. 2.) To characterize the role of thermophilic organisms in sinter deposition. 3.) To compare the structure of sinter with that of putative biological structures in the oldest sedimentary rocks on Earth. 4.) To evaluate which features of sinter are diagnostic of biological influences to aid in possible identification of organisms during planetary exploration.

Findings: Our investigations to date have focused on the hydrodynamic controls on the structuring and morphology of siliceous sinter facies around alkaline hot springs and geysers in Yellowstone. Our work can be divided into 2 substudies: 1.) an investigation of low-temperature (<73 degrees C) sinter facies, where cyanobacterial mats play a significant role in the structuring and development of sinter at all observational levels; and 2.) an investigation of high-temperature (>73 degrees C) sinter facies where thermophilic bacteria may play a role in mediating silica precipitation rates and influence microstructuring and microtextures, but where hydrodynamics are the primary control on the development of sinter macrostructures. Ph.D. student Deena Braunstein continued her fieldwork studying high-temperature sinter in Yellowstone, making one trip to the park in September 1998. She gathered additional data on the hydrodynamic behavior and structuring and morphology of siliceous sinter deposited around a variety of alkaline siliceous hot springs and geysers. This information has been used to define and characterize a variety of hot spring "types". The relationship between hot spring and geyser hydrodynamics and the morphology and structuring of associated siliceous sinter is the subject of the first chapter in her doctoral thesis. In addition, she collected sinter growth experiments started in 1996 and 1997.

Dr. Lowe continued his investigations at Steep Cone Spring, which has been a site of detailed photo-documentation of sinter growth rates for several years. In addition, growth-rate experiments were collected from the Buffalo Pool Group and Five Sisters Springs, and new experiments were installed at these sites and in Coral Pool in Shoshone Geyser Basin.

Findings: We have classified a limited suite of alkaline siliceous hot spring types, based on hydrodynamics and sinter morphology: 1.) non-boiling springs, including non-surging and gently surging springs; 2.) boiling springs, including non-surging and strongly surging springs; and 3.) geysers, including sputtering, fountain and cone types. The primary hydrodynamic factors include: degree of submergence, convection and discharge related circulation, surging (i.e., periodic water level fluctuations), wave activity and splash, and eruption frequency. Our results continue to emphasize that hydrodynamics play the primary role in high temperature sinter development in that it ultimately controls wetting/drying locations and rates, and thus, silica precipitation. Although benthic bacterial biofilms are widely if not ubiquitously present in subaqueous and splash zones, their influence on sinter deposition and macroscopic structuring remains uncertain.

Title: **Volcano Emissions**

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Additional Investigators: Dr. Terrence Gerlach, Mr. Michael Doukas

Objectives: Survey and characterize carbon dioxide emissions from Yellowstone soils and thermal areas in order to identify possible areas of anomalous degassing from depth, and to provide a baseline with which to compare future surveys of carbon dioxide in the event of volcanic unrest. The study involves airborne measurements of carbon dioxide and other gases in the air above the park, as well as ground measurements of carbon dioxide soil efflux within the park.

Findings: Several areas of carbon dioxide efflux have been measured within the park that are greater than what would be expected from normal biologic activity in the soil. In addition, several carbon dioxide plumes from various sources within Yellowstone were successfully measured in the air above the park in 1998 utilizing sensitive instrumentation mounted in fixed-wing aircraft. The detailed analysis of data is not yet complete.

Title: **Holocene and Modern Geomorphic Response to Fires, Floods, and Climate Change in Yellowstone National Park; Natural and Anthropogenic Influences on Stream Systems**

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Additional Investigators: Paula M. Watt

Objectives: The extensive 1988 Greater Yellowstone Area (GYA) fires constitute a landscape disturbance of rare magnitude, and one with important ecological, geomorphic, and climatic implications. In order to provide a longer-term perspective on this event, we propose to investigate the history of Holocene sedimentation in northeastern Yellowstone, using actualistic study of modern fire-related and pre-fire sedimentation as a guide for interpretation of the stratigraphic record. A detailed, highly dateable record of Holocene fire-related sedimentation events is preserved in alluvial and colluvial deposits of the Soda Butte Creek drainage. Comparison of the timing of fire-related events with paleobotanical and climate proxy records can elucidate the relative importance of changing vegetation and hydrological regime, wildfire effects, and intrinsic thresholds in the geomorphic system. Recent changes in stream channels determined through analysis of airphotos, historical photos, and re-surveying will be evaluated in the context of flood history, changes in riparian vegetation, and intrinsic characteristics of basins and channels. We will also examine historical records of meteorological and regional atmospheric conditions associated with both extensive fires and large floods in the GYA, and attempt to develop analogs for climate associated with fire-related sedimentation and other hydrological processes. This research will help to assess the short-term geomorphic response to the 1988 GYA fires, as well as indicate possible consequences of potential global warming and climatic change for stream ecosystems and landscapes in the GYA ecosystem. We are also investigating the effects of a dam-break flood, which washed acid-generating and metals-rich mine tailings down Soda Butte Creek from the Cooke City area into Yellowstone National Park.

Findings: The geomorphic response to fires component of the project is largely complete and results are detailed in several publications. The flood history component is ongoing; we have identified major floods on the Lamar River system of substantially greater peak discharge than the 1996 and 1997 floods (the largest in gauge records): in 1918, the early 1870s and possibly near 1800. Preliminary results of this work are published in a 1995 *Friends of the Pleistocene Field Guide* available from Meyer. We have also collected a large amount of data on the map distribution, metals concentration, and particle size of floodplain mine tailings deposits along Soda Butte Creek, and have estimated their total volume and mass. Copper and lead concentrations are of particular concern. We have also reconstructed the dam-break flood, a high discharge but short duration event.

Title: **Volcanic and Hydrothermal Studies of Yellowstone National Park: Part 1: Anisotrophic Magnetic Susceptibility of Ignimbrites of the Yellowstone Plateau Volcanic Field. Part 2: Magnetic Susceptibility and Remanence Measurements of Selected Rocks. Part 3: Assessment of Hydrothermal Explosion Deposits in Yellowstone National Park. Part 4: Geochemical Studies of Thermal Fluids in YNP.**

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Additional Investigators: Dr Robert L. Christiansen, Dr. Wayne C. Shanks

Objectives: 1.) To assess the validity of using anisotropic magnetic susceptibility as a flow direction indicator in ignimbrites focusing on the Lava Creek Tuff with less emphasis on other volcanic units in the Yellowstone Plateau volcanic field. I plan to examine the ignimbrites in various conditions including a wide of degree of alteration states, proximity to the Yellowstone Caldera, influence of pre-existing topography, stratigraphic positions within a particular exposure, etc.. Measurements will be compared with field data. 2.) To estimate locations of the individual volcanic vents and assess the structure of Yellowstone caldera in relation to caldera forming processes. 3.) To collect oriented core samples and hand samples of various lithologies, primarily volcanic in composition, for magnetic susceptibility and remanence measurements. These measurements will be used in evaluating results from detailed aeromagnetic surveys currently being conducted. The oriented core samples will be collected using a gasoline-powered drill: cores are 1" in diameter and 3-4" long; about 10-12 samples distributed over 6-12 meters distance are collected for each site. Care will be taken to fill the core holes. 4.) To examine the character, extent, age, composition, and triggering mechanisms of hydrothermal explosion deposits identified in Yellowstone National Park, with emphasis on those north of Yellowstone Lake.

Findings: 1.) Multiple sites in the Lava Creek Tuff were collected and analyzed to test the technique using anisotropy of magnetic susceptibility as a flow direction indicator suggest this is a promising tool and yield consistent results. We will continue to collect and analyze more samples in FY99. We are also studying the effects of hydrothermal alteration on magetic susceptibility for the Lava Creek Tuff and will be analyzing our samples for alteration minerology and stable isotopic data. 2.) In FY98, we began our hydrothermal explosion breccia study. We currently have samples submitted for radiocarbon analyses, stable isotopes, alteration mineralogy, and fluid inclusion analyses. We plan on continuing our fieldwork and analyses in FY99. 3.) Studies on the magnetic properties of volcanic and sedimentary rocks in conjunction with our analysis and interpretation of the high resolution aeromagnetic survey of YNP are ongoing and will continue in FY99. A manuscript on this data and interpretation is in progress. 4.) Stable isotopes and geochemistry of stream, lake, and thermal waters are being used to understand the origin of geothermal systems. In FY99, field and laboratory work will continue.

Title: **Sulfur Speciation and Redox Processes in Mineral Springs and their Drainages**.

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Additional Investigators: Dr. Martin Schoonen, Dr. Gordon Southam

Objectives: The primary objectives are to determine the actual speciation of dissolved sulfur species as they undergo oxidation and volatile losses for H_2S, and to study the evolution of acidic drainages unaffected by pyrite oxidation. Intermediate sulfoxy anions, such as thiosulfate, have been implicated as complexing agents to solubilize and mobilize metals in the formation of ore deposits and as monitors of volcanic activity. We hope to relate sulfur speciation in hot springs and their overflow drainages to rates of oxygen diffusion and solubility. We also hope to learn how the chemistry of acidic drainages dominated by elemental sulfur oxidation differs from those dominated by pyrite oxidation.

Findings: Two USGS Open-File Reports containing analyses of 99 hot spring, geyser, and surface water samples from 1974-75 sampling, and 42 samples from 1994-95 sampling, have been published and are available for free from the senior investigator. A proceedings paper summarizing the occurrence and interpretation of thiosulfate in Yellowstone waters has also been published.

During the 1997 field season, eleven water samples were collected from springs in Norris Geyser Basin and from Brimstone Basin, southeast of Yellowstone Lake. During the 1998 field season, twenty-two water samples were collected from Norris Geyser Basin, Gibbon Geyser Basin, Heart Lake Fissure Group, and Brimstone Basin. Sampling and onsite analysis was made possible with a mobile laboratory equipped with an ion chromatograph, a portable UV-visible spectrophotometer, a diode-array spectrophotometer, and an autotitrator. In 1997, little or no thiosulfate was found at most locations. Thiosulfate concentrations were significantly high at Cinder Pool and Cistern at Norris. A detailed geochemical interpretation of the sulfur redox chemistry at Cinder Pool, and a survey of H_2S, S_2O_3, and SO_4 in hot spring waters is part of a Ph.D. thesis by Yong Xu (SUNY-Stony Brook), submitted for publication in 1997. Both water sampling (for major and trace elements) and microbial sampling were completed for seven sites along Alluvium Creek and at Brimstone Basin in 1997. Unusual aquatic larval and microbial communities and extremely acidic waters (pH 1.8-3.0) from elemental sulfur oxidation were found. Detailed geochemical interpretations of the sulfur redox chemistry at Cinder Pool and a survey of H_2S, S_2O_3, and SO_4 in hot spring waters in the park are scheduled for publication early this year.

Title: **Impact of Fires of 1988**

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Objectives: Assess the impact of the Yellowstone fire ash upon the groundwater geochemistry. Continue the collection, processing, and chemical analysis of ash, soil, and plant material from selected sites within the park. Collect fire-related samples from 15 selected burn areas of both ash and soil to determine annual change in physical and chemical properties, and to document with photographs.

Findings: During the September 1997 field operation in Yellowstone, several sites were observed, photographed, and sampled. These were the sites at Old Faithful and Lewis River. It was determined that the ash layer was maintained much like previous years and the slow growth of Lodgepole Pine was again observed. Samples of ash and soil were analyzed in the laboratory and sieved as in the previously reported procedure. Samples are available for water extraction and chemical determinations as previously accomplished.

Selected sites were sampled in September 1998 at different types of elevation and terrain.

Title: **Quaternary Geology, Geoarcheology, Neotectonics, and Hazards Studies of the Greater Yellowstone Area**

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Additional Investigators: Ken Cannon, Lisa Morgan

Objectives: 1.) Investigate Yellowstone Lake and River level changes associated with caldera inflation/ subsidence cycles. 2.) Geoarcheology of sites, particularly around Yellowstone Lake. 3.) Hazards appraisal, particularly late Quaternary faulting, hydrothermal explosion, volcanism, and landsliding. 4.) Outreach, including books, training videos, and high quality videos on Yellowstone geology.

Findings: We documented in more detail changes in Yellowstone Lake level. With Ken Cannon, we found a similar geologic expression for the south shore of Yellowstone Lake.

Title: **Trace Element Partitioning Coefficients for Feldspar in High-Silica Rhyolite**

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Additional Investigators: Dr. Don F. Parker, Mr. John White

Objectives: On August 13-14, 1998, we collected six samples of rhyodacite from Yellowstone National Park. These samples have been added to our data set of approximately 55 samples of rhyolite. We hope to use these samples to better constrain the values of partition coefficients between feldspar and liquid during rhyolite petrogenesis.

Findings: We analyzed the Yellowstone samples for major and trace element chemistry during winter-spring of 1998-1999. We are currently preparing mineral separates in order to analyze them, so we may calculate partition coefficients for feldspar. The six Yellowstone samples will be housed in the Baylor Geology department.

Title: **Analysis of Geyser Periocitiy**

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Additional Investigators: Steven Ingebritsen, Paul Silver, Nicholas Bacher

Objectives: Examine variations and geyser periodicity and their controls.

Findings: Geyser periodicity network has been installed. Examination of existing data indicate a small non-linear component in some of the geysers. Some of the geysers respond to both seismicity and variations in atmospheric pressure.

Title: **Yellowstone Paleontological Survey**

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Additional Investigators: William P. Wall

Objectives: Provide comprehensive baseline paleontological resource data to park management in a publication format that is presented in a park management perspective. The report will provide recommendations relative to interpretation, protection, resource management, curation, etc. of the park's paleontological resources. The report will generate a paleospecies list, bibliography, updated RMP project statements, and other paleontological resource data for Yellowstone National Park.

Findings: During the 1997 field season, field crews inventoried six new paleontological localities in

Yellowstone. A rare cochliodont crushing tooth from the Mississippian Madison Limestone was discovered and collected. GPS data was collected from the standing petrified trees along Specimen Ridge. Surface exposures of fossilized bone from the Late Cretaceous plesiosaur were collected. The Yellowstone Paleontological Survey Report was completed during late 1997, and will be published by March 1998.

As of 1998, over twenty fossiliferous stratigraphic units have been documented in Yellowstone containing fossil plants, invertebrates, vertebrates, and trace fossils. Yellowstone preserves an extensive geologic record ranging from the Precambrian through the Holocene. Except for the Silurian, rocks of nearly every geologic time period are exposed within the boundaries of the park.

Title: **Operation and Development of an Earthquake and Volcano Information System at Yellowstone National Park**

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Additional Investigators: Sue Nava, Charles Meertens

Objectives: The primary objectives of the Yellowstone seismic and GPS networks are to monitor and assess seismicity and ground deformation that may be related to both volcanic and tectonic earthquake activity. The project tasks include maintenance, recording, routine analyses, and station installation of the Yellowstone Seismograph and GPS Networks (YSN). Data from the YSN provide information for public safety, park and surrounding community management and planning, public information and interpretation, and for scientific research interests. The YSN is designed to monitor earthquakes of the entire Yellowstone volcanic system, including Yellowstone National Park (YNP) and the nearby Hebgen Lake fault zone. The GPS stations provide continuous monitoring of the crustal deformation of the volcanically active Yellowstone caldera. This monitoring system provides real-time earthquake surveillance by a recently upgraded 22-station, 32-component, seismic network telemetered via FAA microwave links (at no cost to the project) to Salt Lake City, Utah, and digitally recorded at the University of Utah Seismograph Stations. Continuous GPS data are recorded at two sites and are archived at UNAVCO (accessible via the Internet). The USGS Volcano Hazards Program jointly funds this cooperative project with partial support form the National Park Service (NPS) for field work. The primary products for this USGS support are annual earthquake catalogs, the services of a regional earthquake and GPS recording and information center, including timely release of unusual earthquake activity reports to the USGS and the NPS.

Findings: In addition to routine network operations, notable efforts under this cooperative agreement during the report period related to: 1.) Continued upgrading and maintenance of seismograph stations against the harsh winter conditions of Yellowstone. This included, (a) continued installation of audio bandpass filters at relay sites in order to reduce interference; (b) replacement of several aging radio transmitters and receivers throughout the network; and (c) VCO system repairs and upgrades. GPS quality station locations continue to be determined using Trimble SSI dual-frequency receivers. Seventy-seven percent (17/22) of the stations of the Yellowstone seismograph network were visited for maintenance during the report period. 2.) Installation of a three component, broadband, digitally-telemetered seismograph station on the northwest side of the Yellowstone caldera at Madison River. Field installation was completed during the report period, but a labor strike by U.S. West and miscellaneous technical problems with the installation of a telephone link between the Salt Lake City airport and the central recording lab prevented completion of the project during this report period. 3.) Installation of three reconditioned L4 seismometers (Norris Junction, Gravel Pit, and Pelican Cone). Continued upgrade of the central receive sites for all stations in the Yellowstone network (Mt. Washburn, Wyoming, and Sawtelle Peak, Idaho). 4.) Assistance to the USGS-NEIC for maintenance of a cooperative U.S. National Seismograph Station (USNSN) located near Yellowstone Lake. 5.) Installation of a continuously recorded GPS receiver at Mammoth to complement a receiver located at Lake. These stations monitor the deformation of the YNP caldera. Data are automatically retrieved via a dial-up telephone line every 24 hours and then incorporated into the UNAVCO GPS archives. 6.) Maintenance of a continuous recording, high-precision GPS station at the U.S. National Seismograph Station with telemetry provided by the USGS VSAT satellite system. Note that the GPS equipment was provided by the NSF cooperative University ARI funds. Installation costs were supported by NSF funds. 7.) Systematic determination of local magnitudes (M L) and M L station corrections using local USNSN, Montana Wood-Anderson station BUT (Butte, Montana), and Utah broadband stations, for all coda magnitude (M C) 3.0 and greater earthquakes located in the Yellowstone region since January 1, 1994. Analysis continued on the recalibration of the Yellowstone coda magnitude scale. Over 100 Wood-Anderson seismograph records principally from BUT and IRCI (Idaho Falls, Idaho) with supplemental data from USNSN stations at Dugway and Yellowstone Lake were analyzed. 8.) Steps towards submitting 18 years of University of Utah short-period waveform data to the IRIS Data Management Center in SEED format. 9.) Continued software development to integrate new digital data streams with existing analog data streams for routine analysis. 10.) Completion of a network inventory for the CNSS and major progress towards a comprehensive station inventory for the IASPEI handbook. Submission several times per day of earthquake catalog data for the Utah region to the Council of the National Seismic System's composite catalog. 11.) Assistance to the NPS with long-term plans for implementing volcano and earthquake hazard assessment and identifying workforce needs. 12.) Analysis of space-time variations of seismic source mechanisms and related stresses of Yellowstone. Discussions with USGS Menlo Park volcano seismology group regarding implementation of long-period event detection software (within Earthworm), and as part of MS student (G. Waite) thesis research on Yellowstone National Park seismicity.

Title: **Ground Penetrating Radar Studies at Mammoth Hot Springs**

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Additional Investigators: Ms. Laura Joss, Dr. William Sill

Objectives: The purpose of this study was to identify possible geologic risks involved in future construction near Mammoth Hot Springs, Yellowstone National Park. Ground penetrating radar was used to help identify these geologic hazards.

Findings: The Mammoth Hot Springs area features a complex and extensive assemblage of hydrothermal carbonate rocks. Due to the rapid and often haphazard manner in which the associated thermal features emerge and disappear, and because of the highly soluble nature of the rocks themselves, a thorough investigation of the area's subsurface is necessary before large-scale development proceeds. On May 13, 1997, ground penetrating radar (GPR) and spontaneous potential tests were conducted in the Mammoth Hot Springs area. These initial tests were conducted at Opal Terrace, the mail carrier's cabin, and near the icehouse. The results of these initial tests were encouraging, and on June 18, 1997, the Montana Tech of The University of Montana Geophysical and Geological Field Camp collected GPR and vertical electrical sounding (VES) data near the mail carrier's cabin. Moreover, a small test of radar antenna frequencies was conducted near the icehouse at Mammoth Hot Springs on August 4, 1997. GPR was employed to delineate subsurface geometry and detect dissolution features. With a signal penetration depth of over 18 meters and a vertical resolution of 0.4 meters, the GPR survey provided little evidence of large subsurface cavities in the region of the mail carrier's cabin. Those cavities that do exist are either too small or are too deep to be a concern. Possible cavities, however, were detected at Opal Terrace and at the icehouse site. Many anomalies located by the GPR system were interpreted as cultural, or man-made objects. In addition, the presence of small fractures in the area must be considered before any development proceeds. These fractures may be related to historic subsidence. Furthermore, while the area near the mail carrier's cabin currently is geothermally inactive, there is no guarantee that this site will remain inactive in the future. No additional data was collected in 1998. However, three papers for publications were prepared and one of these papers was published in 1998.

Title: **Low 18-Oxygen Rhyolites in YNP: Using Zircons to Establish the Timing and Mechanisms for 18-Oxygen Depletion in Granitic Magmas**

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Additional Investigators: Dr. Ilya Bindeman

Objectives: 1.) To determine magmatic geochemistry of volcanic rocks within the Yellowstone Caldera. 2.) To elucidate the importance of hydrothermal fluids in altering rock compositions. 3.) To determine the causes of low oxygen-18 magmas.

Findings: Samples were collected in July 1996. Samples were prepared in Madison during 1997-98, and isotope analyses were started in 1998. Additional sampling is planned for 1999.

Title: **Eruption History of the Sepulcher Formation as Determined by Geochemistry**

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Additional Investigators: Dr. Harold Coffin

Objectives: To use geochemical analyses and statistical methods in the analysis of the breccia and rock and ash samples from Yellowstone Fossil Forest located in the Specimen Creek area in attempts to clarify the origin and history of the breccia flows and the petrified trees that are buried by them.

Findings: During 1997, only two days were spent in the field. The remainder of the research time has been used to complete the laboratory analyses of the samples and the statistical analyses of the data. Statistical analysis is almost complete, however from the data it has become evident that there are at least two sites within the study area which must be re-sampled. In 1998, two sites were re-sampled for analyses and a GPS Survey of the major fossil trees within the Specimen Creek Area was conducted. The ash samples were submitted for analyses and the data is currently being analyzed. The GPS data will be transferred to an expanded topographic map and submitted later.

Title: **Groundwater-Flow Assessment of the Upper Soda Butte Creek Drainage Basin, Park County, Montana and Wyoming**

Principal Investigator: Dr. Willis Weight
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Additional Investigators: Amy Huskey, Alan English

Objectives: To understand the basic hydrogeology of the Upper Soda Butte Drainage from Silver Gate to Cook City. Characterization will be performed through performing pumping tests, static water-level surveys, and stream gauging. Additional analysis of the role of bedrock is to be explored. The data will be integrated into a groundwater flow model.

Findings: Three aquifer tests were performed and water level surveys were conducted in summer and fall 1997, and throughout the fall of 1998. Stream gauging was performed. A groundwater flow model using a graphical interface, GMS, was used to create a three-layer model of the area. This was put together as part of an MS thesis by Amy Huskey. She defended her thesis, but corrections are still underway. Alan English is continuing a thesis study in the Silver Gate area, including water-quality data.

Title: **Postglacial Fire Frequency and its Relation to Long-Term Vegetational and Climatic Changes in Yellowstone Park**

Principal Investigator: Dr. Cathy Whitlock

See Fire

Title: **Hydrothermally-Affected Soils of Yellowstone National Park**

Principal Investigator: Dr. Michael A. Wilson
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Additional Investigators: Ann W. Rodman, Henry F. Shovic

Objectives: 1.) Document field and laboratory characteristics of selected acid sulfate and neutral chloride soils within Yellowstone National Park. 2.) Determine pedological and landscape genetic processes relative to alteration chemistry in selected hydrothermal areas. 3.) Investigate mineral stability and secondary mineral formation in both neutral chloride and acid sulfate environments.

Findings: Field investigations in 1998 focused on: 1.) Range and variability of soil properties in the Lower Geyser Basin. In part, we are examining vegetational patterns relative to soil characteristics. Soil samples currently being analyzed. 2.) Diurnal and seasonal variability of soil temperature in both acid sulfate and neutral chloride areas. Preliminary data was collected in 1998.